VEHICLE SYSTEMS

CO-CHAIRMAN
TOM BALES
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JACK SUDDRETH
TOM WHEELER

VEHICLE SYSTEMS PANEL

EXPENDABLE LAUNCH VEHICLES AND CRYOTANKS
SUBPANEL REPORT

THOMAS BALES
SUBPANEL CHAIRMAN

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INTRODUCTION

PERSPECTIVES OF THE SUBPANEL ON EXPENDABLE LAUNCH VEHICLE STRUCTURES AND CRYOTANKS

- NEW MATERIALS PROVIDE THE PRIMARY WEIGHT SAVINGS EFFECT ON VEHICLE MASS/SIZE
  - PROVIDE ROBUSTNESS IN DESIGN
  - YIELD SYSTEMS COST SAVINGS

- TODAY'S INVESTMENT
  - DISPROPORTIONATELY SMALL
  - SIGNIFICANT BENEFITS APPARENT
  - NO FOCUSED PROGRAMS IN MATERIALS AND STRUCTURES TECHNOLOGIES WITHIN NASA FOR LAUNCH VEHICLES

- TYPICALLY 10-20 YEARS TO MATURE AND FULLY CHARACTERIZE NEW MATERIALS
  - MANUFACTURING PROCESSES MUST BE DEVELOPED CONCURRENTLY
  - USER NEEDS CAN ACCELERATE MATERIALS DEVELOPMENT
    - SELECTED EXAMPLES (8090, 2219, 7XXX)
VEHICLE SYSTEMS

TECHNOLOGY NEEDS ADDRESSED BY THE EXPENDABLE LAUNCH VEHICLES AND CRYOTANKS SUBPANEL

- MATERIALS DEVELOPMENT
  - ADVANCED METALLICS
  - COMPOSITES
  - TPS/INSULATION

- MANUFACTURING TECHNOLOGY
  - NEAR NET-SHAPE METALS TECHNOLOGY
  - COMPOSITES
  - WELDING

- NDE
### EXPENDABLE LAUNCH VEHICLES AND CRYOTANKS

#### VEHICLE SYSTEMS PANEL

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>MILESTONES &amp; RESOURCE REQUIREMENTS</th>
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<tbody>
<tr>
<td>• ADVANCED STRUCTURAL MATERIALS</td>
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<thead>
<tr>
<th>BACKGROUND &amp; RELATED FACTORS</th>
<th>RECOMMENDED ACTIONS</th>
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<tbody>
<tr>
<td>• IN THE LAST 10 YEARS, MANY NOVEL MATERIALS HAVE BEEN DISCOVERED THAT HAVE APPLICABILITY TO SPACE PROGRAMS</td>
<td>• EVALUATE THE APPLICATION AREAS AND STATE OF MATURITY OF THESE NEW MATERIALS</td>
</tr>
<tr>
<td>• THESE INCLUDE BUT ARE NOT LIMITED TO:</td>
<td>• DESIGN AND ANALYTICAL TOOL TO REALISTICALLY CALCULATE COST AND WEIGHT BENEFITS ARISING FROM INCORPORATION OF SUCH MATERIALS</td>
</tr>
<tr>
<td>• ULTRA LIGHTWEIGHT AL ALLOYS</td>
<td>• PRIORITIZE AND SELECT FOR FUNDING THE SEVERAL MATERIALS THAT OFFER THE MOST SIGNIFICANT PAY-OFF IN THE 3-10 YEAR TIME FRAME</td>
</tr>
<tr>
<td>• METAL MATRIX COMPOSITES</td>
<td>• INSIST ON A TEAMING APPROACH THAT INCLUDES NASA, PRODUCERS AND USERS AND INVOLVES SELECTION, DESIGN, MANUFACTURING, AND ENGINEERING CRITERIA</td>
</tr>
<tr>
<td>• POLYMER BASED COMPOSITES</td>
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<tr>
<td>• DEVELOPMENT OF THESE MATERIALS TO MATURITY, AND APPLICATION IN NASA PROGRAMS, WILL HAVE A PROFOUND INFLUENCE ON WEIGHT AND COST SAVINGS AS WELL AS TECHNOLOGICAL IMPACT</td>
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### DESCRIPTION:

<table>
<thead>
<tr>
<th>NEAR NET SHAPE FABRICATION TECHNOLOGY FOR VEHICLE STRUCTURES</th>
<th>MILESTONES &amp; RESOURCE REQUIREMENTS</th>
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<tr>
<td>• CURRENT VEHICLE SYSTEM STRUCTURES EMPLOY CONVENTIONAL MATERIALS AND FABRICATION TECHNOLOGY</td>
<td>• INITIATE AGGRESSIVE TECHNOLOGY DEVELOPMENT PROGRAM TO DEMONSTRATE FORMING AND JOINING PROCESSES SUITABLE FOR ALL APPROPRIATE VEHICLE SYSTEM STRUCTURES</td>
</tr>
<tr>
<td>• RESULTANT STRUCTURES ARE TYPICALLY HIGH COST AND WEIGHT PENALTIES ARE BUILT INTO THE DESIGN</td>
<td>• IDENTIFY VEHICLE STRUCTURES DESIGN CONCEPTS AND REQUIREMENTS AMENABLE TO NEAR NET SHAPE PROCESSING</td>
</tr>
<tr>
<td>• NUMEROUS NEAR NET SHAPE FABRICATION OPPORTUNITIES EXIST, EMPLOYING FORMING AND JOINING TECHNOLOGIES WHICH ARE RECOGNIZED, BUT REQUIRE DEVELOPMENT</td>
<td>• SELECT NEAR NET SHAPE PROCESSES AMENABLE TO VEHICLE HARDWARE</td>
</tr>
<tr>
<td>• PAYOFFS WILL INCLUDE SIGNIFICANT IMPROVEMENTS IN PERFORMANCE AND LOWER FABRICATION AND TOTAL PROGRAM COSTS</td>
<td>• DEVELOP CANDIDATE HARDWARE PROGRAM TO DEMONSTRATE/VALIDATE FABRICATION TECHNOLOGY</td>
</tr>
</tbody>
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<tr>
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<td>VEHICLE SYSTEMS PANEL</td>
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<tr>
<td>• NDDE OF ADVANCED STRUCTURES</td>
<td>• NDE PROCESSES TO EVALUATE INCLUDE:</td>
</tr>
<tr>
<td>• NEED AUTOMATED REAL-TIME TECHNIQUES TO REDUCE COST</td>
<td>• REAL-TIME X-RAY</td>
</tr>
<tr>
<td>• HIGHER-STRENGTH MATERIALS NEED MORE RELIABLE NDE</td>
<td>• REAL-TIME ULTRASONICS</td>
</tr>
<tr>
<td>• FRACTURE TOUGHNESS DRIVEN DESIGNS REQUIRE PRECISE FLAW IDENTIFICATION/DETECTION</td>
<td>• ACOUSTIC EMISSION</td>
</tr>
<tr>
<td>• INCORPORATE AUTOMATION FEATURES</td>
<td>• EDDY CURRENT</td>
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<tr>
<td>• EVALUATE BUILT-IN SENSORS FOR COMPOSITES</td>
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<tr>
<td>• SPACE PROGRAMS REQUIRE UNIQUE LIGHT WEIGHT MATERIALS</td>
<td>• FUND GOVERNMENT, INDUSTRY, AND PRODUCER PROGRAM TO ACCELERATE NEAR-TERM AND FAR-TERM AI-LI DEVELOPMENT</td>
</tr>
<tr>
<td>• ALLOYS DEVELOPED FOR COMMERCIAL AND MILITARY AIRCRAFT NOT DIRECTLY APPLICABLE</td>
<td>• TAILOR MATERIALS DEVELOPMENT WITH SELECTED MANUFACTURING PROCESSES</td>
</tr>
<tr>
<td>• MATERIAL PRODUCERS ARE NOT CURRENTLY PLANNING TO INDEPENDENTLY DEVELOP THE REQUIRED LAUNCH VEHICLES' ALLOYS, DEVELOPMENT WILL BE MARKETUSER DRIVEN</td>
<td>•</td>
</tr>
<tr>
<td>• NEAR-TERM AI-LI ALLOYS CAN PROVIDE UP TO 15 PERCENT WEIGHT SAVINGS, LONGER-TERM ALLOYS HAVE POTENTIAL WEIGHT SAVINGS UP TO 30 PERCENT</td>
<td>•</td>
</tr>
<tr>
<td>• AI-LI ALLOYS PROVIDE UNIQUE PROCESSING OPTIONS, E.G. SUPERPLASTIC FORMING</td>
<td>•</td>
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<tr>
<td>• LACK OF COE R FUNDING LIMITS EFFECTIVENESS OF BRIDGING PROGRAM</td>
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</table>
**BENEFITS OF USING AL-LI ALLOYS FOR CRYOGENIC TANKS**

- 15% tank weight savings due to improved specific properties
- 80% raw material weight savings due to reduced scrap rate (80:20)

### Al-Li Integrally machined Tank
- Tank weight: 42.5K lbs
- Raw material: 213K lbs
- Material costs:
  - $1.0 M
  - $4.2 M
  - $3.2 M
- System costs savings:
  - $3.2 M
  - $15.0 M
  - $11.8 M

### Al-Li Built-up structure
- Tank weight: 42.5K lbs
- Raw material: 51K lbs
- Material costs:
  - $1.0 M
  - $1.0 M
  - 0
- System costs savings:
  - $15.0 M

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**EXPENDABLE LAUNCH VEHICLES AND CRYOTANKS VEHICLE SYSTEMS PANEL**

### DESCRIPTION:
- Composite technology for cryotanks and dry bay structures (with emphasis on fiber reinforced plastic systems)

### MILESTONES & RESOURCE REQUIREMENTS:

### BACKGROUND & RELATED FACTORS:
- Processes must be defined to account for FRP manufacturing capabilities
- A totally integrated materials, design, manufacturing, inspection, and testing process must be identified which will account for the unique process needs and capabilities of composites
- Weight reduction potential is 20-30 percent

### RECOMMENDED ACTIONS:
- Establish composite cryotank system design requirements. Identify liner requirements
- Determine state-of-the-art capabilities in FRP composites for materials, design, manufacturing, inspection and testing. Specifically consider the following:
  - In-line inspection
  - In-situ cure methodology
  - Tooling approach
  - Joining technology
  - Composite damage tolerance and repair
  - Design a baseline cryotank
  - Conduct manufacturing process trades
  - Establish a baseline manufacturing process
  - Define facility size required to support FRP
MATERIALS AND STRUCTURES TECHNOLOGY FOR SPACE TRANSFER VEHICLES

Cryotank
- Materials
  - Al-Li
  - SiCp/Al MMC
  - Ti
  - RMC
- Low cost fabrication
  - Spun formed domes
  - SPF, Built-up structure
  - Filament wound
  - RMC tanks
- Explosively formed components

Core primary structure
- Materials
  - Al-Li
  - B/Al MMC
  - Gr/E
- NDE/durable materials
  - Real time radiography
  - Advanced ultrasonics
  - Space hardened materials
  - Protective coatings/platings

Benefits
- Advanced materials: 20-30% weight savings
  Increased payload
  Greater range
- Low cost fabrication: 30% cost savings
  Reduced assembly time
- NDE/durable materials: Increased reliability and vehicle life

EXPENDABLE LAUNCH VEHICLES AND CRYOTANKS
VEHICLE SYSTEMS PANEL

DESCRIPTION:
- WELDING
  - PROCESS UNDERSTANDING, OPTIMIZATION, AND AUTOMATION FOR JOINING STRUCTURES

MILESTONES & RESOURCE REQUIREMENTS:

BACKGROUND & RELATED FACTORS:
- WELDING USED AS JOINING TECHNIQUE ON ALL MAJOR AEROSPACE HARDWARE
- REPAIR OF WELDING DEFECTS MAJOR COST IN MANUFACTURING
- HUMAN ERRORS A MAJOR CAUSE OF WELDING DEFECTS
- LACK OF UNDERSTANDING OF PROCESS VARIABLES AND THEIR INFLUENCE ON PROPERTIES
- AUTOMATION POTENTIALLY CAN REDUCE NDE

RECOMMENDED ACTIONS:
- IDENTIFY PROCESS VARIABLES RELATIONSHIPS
- DEVELOP PROCESS MODELS
- IDENTIFY AND DEVELOP SENSORS FOR PROCESS MONITORING AND FEEDBACK
- IDENTIFY AND DEVELOP CONTROL HARDWARE AND SOFTWARE
- VERIFY AND VALIDATE PROCESSES AND CONTROLS
EXPENDABLE LAUNCH VEHICLES AND CRYOTANKS
VEHICLE SYSTEMS PANEL

DESCRIPTION:
• NEAR NET-SHAPE METALS TECHNOLOGY
  - BUILT-UP STRUCTURES FOR CRYOGENIC TANKS AND DRY-BAY APPLICATIONS

MILESTONES & RESOURCE REQUIREMENTS:

BACKGROUND & RELATED FACTORS:
• INTEGRALLY STIFFENED STRUCTURES FABRICATED BY MACHINING FROM A THICK PLATE RESULTS IN HIGH SCRAP RATES (85%)
• LOW BUY-TO-FLY RATIO REQUIRED FOR ECONOMIC UTILIZATION OF NEW HIGH PERFORMANCE METALS
• BUILT-UP STRUCTURE APPROACH IS APPLICABLE TO BROAD RANGE OF STRUCTURAL COMPONENTS ENCOMPASSING TANKS AND DRY-BAY STRUCTURES
• PAYOFFS WILL INCLUDE SIGNIFICANT IMPROVEMENTS IN PERFORMANCE AND LOWER FABRICATION COST

RECOMMENDED ACTIONS:
• IDENTIFY VEHICLE STRUCTURES, DESIGN CONCEPTS AND REQUIREMENTS AMENABLE TO BUILT-UP STRUCTURE APPROACH
• DEVELOP FORMING AND JOINING PROCESS TO FABRICATE APPROPRIATE STRUCTURAL PREFORMS
• DESIGN, FABRICATE AND TEST STRUCTURAL SUBELEMENTS
• DEMONSTRATE STRUCTURAL INTEGRITY UNDER REALISTIC SERVICE CONDITIONS
• VALIDATE TECHNOLOGY THROUGH DESIGN, FABRICATION AND TESTS OF FULL-SCALE TANKS AND DRY-BAY STRUCTURAL ARTICLES

SUMMARY OF THE DELIBERATIONS OF THE EXPENDABLE LAUNCH AND CRYOTANKS SUBPANEL

• THE MAJOR NEAR TERM ISSUE FOR ALL IS WHETHER FUNDING WILL BE PROVIDED TO ASSURE INCORPORATION IN THE NLS
  - PRODUCTION CAPABILITY IS IN PLACE FOR 8090, WELDALITE, AND 2090
  - NEAR NET SHAPE PROCESSES HAVE BEEN DEFINED AND SCALE UP ACTIVITIES ARE UNDERWAY
  - PROGRAM MANAGEMENT DECISIONS ARE REQUIRED TO EXPLOIT POTENTIAL
• MATERIALS TECHNOLOGY PROGRAMS WITHIN NASA ARE TOO LIMITED/RESTRICTIVE
  - NO FOCUSED PROGRAMS IN MATERIALS AND STRUCTURES TECHNOLOGIES WITHIN NASA FOR LAUNCH VEHICLES
  - CLEAR NEED FOR SUSTAINED/CONTINUING PROGRAMS TO SUPPORT USER NEEDS/LONG TERM NASA MISSIONS
• SIGNIFICANT NEEDS EXIST FOR STRUCTURAL ANALYSIS AND OPTIMIZATION PROGRAMS
• NDE TECHNIQUES AND METHODS MUST BE EXPLOITED TO ASSURE INTEGRITY, RELIABILITY AND COST REDUCTIONS
• JOINING AND BONDING TECHNIQUES AND CONCEPTS MUST BE DEVELOPED AND CHARACTERIZED FOR FUTURE LARGE LAUNCH VEHICLE APPLICATIONS
REUSABLE VEHICLES SUBPANEL
ISSUE/TECHNOLOGY REQUIREMENTS

PERSPECTIVES
• FUTURE VEHICLES REQUIRE LOW COST, HIGH RELIABILITY, ROBUSTNESS, LOW MAINTENANCE, ON-TIME LAUNCH CAPABILITY
• CURRENT TECHNOLOGY GAPS EXIST RELATIVE TO ACCOMPLISHING THE ABOVE GOAL
• MAJOR TECHNOLOGY CATEGORIES
  - MATERIALS
  - STRUCTURAL CONCEPTS
  - FABRICATION/MANUFACTURING
  - DESIGN/ANALYSIS/CERTIFICATION
  - NON-DESTRUCTIVE EVALUATION (NDE)

MAJOR PAYOFF ITEMS

<table>
<thead>
<tr>
<th>MATERIALS</th>
<th>STRUCTURAL CONCEPTS</th>
<th>FABRICATION/MANUFACTURING</th>
<th>DESIGN/ANALYSIS/CERTIFICATION</th>
<th>NDE</th>
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<tbody>
<tr>
<td>COMPOSITES</td>
<td>NEAR NET SHAPES</td>
<td>BOND</td>
<td>CRITERIA</td>
<td>DESIGN FOR INSPECTABILITY</td>
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<tr>
<td>AI-LI</td>
<td>INTEGRALLY-MACHINED</td>
<td>WELD</td>
<td>SYSTEMS OPTIMIZATION</td>
<td>HEALTH MONITORING</td>
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<tr>
<td>TPS</td>
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<td>EXTRUDE</td>
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DESCRIPTION:
• IN SPACE JOINING
  - WELDING
  - BONDING

MILESTONES & RESOURCE REQUIREMENTS:

BACKGROUND & RELATED FACTORS:
• REPAIR TECHNIQUES FOR IN SPACE HARDWARE REQUIRED
• IN SPACE ASSEMBLY TECHNIQUES FOR LARGE STRUCTURES
• WELDING AND BONDING PROVIDE HIGH WEIGHT, LEAK PROOF STRUCTURES
• SOVIETS HAVE MADE EMERGENCY WELDING REPAIR ON MIR
• ELECTRON BEAM PROCESS ONLY PROCESS PRESENTLY USED IN VACUUM

RECOMMENDED ACTIONS:
• IDENTIFY AND DEVELOP WELDING AND BONDING PROCESSES FOR IN SPACE USE
• IDENTIFY LIMITING FEATURES OF ARC WELDING PROCESSES FOR USE IN SPACE
• DEVELOP WELDING HARDWARE/SOFTWARE FOR SPACE USE
• IDENTIFY SAFETY ISSUES ASSOCIATED WITH WELDING IN SPACE
• DEVELOP REMOTE CONTROL AND MANIPULATORS FOR OPERATIONS
• PLAN AND CONDUCT PROOF OF EXPERIMENT FOR SHUTTLE FLIGHT

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<th>DESCRIPTION:</th>
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<tr>
<td>• Damage tolerant design for composite structures</td>
<td>• Publish damage tolerant design data book for composite structure</td>
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<tr>
<td>• Space transportation missions are weight driven</td>
<td>• Develop damage tolerant philosophy/criteria</td>
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<tr>
<td>• Composites reduce weight, reduce part count and are adaptable to complicated shapes</td>
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<tr>
<td>• Unless properly designed, easily damaged</td>
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<tr>
<td>• Goal: visually inspect only with minimal impact on weight</td>
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<td></td>
<td>• Assemble industry available test data</td>
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<td>• Identify candidate fibers, resins, lay-ups, and manufacturing processes for damage tolerant skin designs</td>
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<tr>
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<td>• Develop designed experiment utilizing damage tolerant testing to identify drivers (temperature range R.T. to 800°F)</td>
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<td>• Utilize best skin designs for honeycomb panels and perform designed experiment to again identify drivers (temperature range R.T. - 800°F)</td>
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<td>• Optimized system engineering approach to ensure robustness</td>
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<td>• Low margins in the ascent operational envelope increases operational cost</td>
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<tr>
<td>• Maintenance and refurbishment of low-life parts is costly in inspection, analysis and change-out</td>
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<td>• Robustness provides lower total cost, less rework, launch time, higher performance and less complex operation</td>
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<td></td>
<td>• Develop concurrent engineering tools for flight mechanics, control, performance, leads, aeroelasticity, manufacturing, operations, etc...</td>
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<td>• Develop inter-disciplinary, total cost optimization and trades analysis tools</td>
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<td>• Develop accurate statistical quantification tools for all sensitive parameters</td>
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<td></td>
<td>• Develop atmospheric (winds) characteristics for design and operation</td>
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<td></td>
<td>• Analytical tools to more accurately predict aerodynamics, plumes, acoustical, etc... induced environment data CFD</td>
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<td>• Develop model synthesis tools to reduce model development</td>
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<td>• Develop system probabilistic tools to guide optimization criteria</td>
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# REUSABLE LAUNCH VEHICLES AND CRYOTANKS
## VEHICLE SYSTEMS PANEL

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<td>• MAINTENANCE AND REFURBISHMENT PHILOSOPHY</td>
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<tr>
<td>• CURRENT REUSABLE SPACE VEHICLES ARE ESSENTIALLY DE-CERTIFIED AS FLIGHT VEHICLES AT THE MOMENT OF TOUCHDOWN</td>
<td>• EXAMINE MAINTENANCE AND REFURBISHMENT PHILOSOPHIES OF NON-SPACE VEHICLE OPERATORS TO IDENTIFY &quot;LESSONS LEARNED&quot; FOR SPACE SYSTEMS</td>
</tr>
<tr>
<td>• RE-CERTIFICATION REQUIRES LARGE SCALE DISASSEMBLY, INSPECTION, AND TEST PRIOR TO NEXT FLIGHT</td>
<td>• DEFINE EXPERIENCE DATA BASE FROM PAST REUSABLE VEHICLE FLIGHTS TO ALLOW STATISTICAL CORRELATION OF SYSTEM FAILURE MODES, EFFECTS, AND FREQUENCIES WITH MAINTENANCE AND REFURBISHMENT APPROACHES</td>
</tr>
<tr>
<td>• THESE ACTIVITIES ARE LABOR INTENSIVE AND ACCOUNT FOR A LARGE PART OF THE OPERATIONS COST OF THE VEHICLE.</td>
<td>• DEVELOP CRITERIA TO DESIGN FOR MAINTENANCE AND ASSEMBLY</td>
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## TECHNOLOGIES

- ADVANCED STRUCTURAL MATERIALS
- AL-LI TECHNOLOGY
- NEAR NET SHAPE FABRICATION TECHNOLOGY FOR VEHICLE STRUCTURES
- NEAR NET SHAPE METALS TECHNOLOGY
- NEAR NET SHAPE EXTRUSIONS FOR STRUCTURAL HARDWARE
- NEAR NET SHAPE: FORGINGS
- NEAR NET SHAPE: SPIN FORGINGS
- WELDING
- IN-SPACE WELDING/JOINING
- COMPOSITES TECHNOLOGY FOR CRYOTANKS AND DRYBAY STRUCTURES
- JOINING TECHNOLOGY FOR COMPOSITE CRYOTANKS
- TOOLING APPROACH FOR MANUFACTURING LARGE DIAMETER CRYOTANKS
- DEVELOP A CURE METHODOLOGY FOR LARGE COMPOSITE CRYOTANKS
- STATE-OF-THE-ART BUCKLING STRUCTURE OPTIMIZER PROGRAM
- STATE-OF-THE-ART "SHELL OF REVOLUTION" ANALYSIS PROGRAM
- NDE FOR ADVANCED STRUCTURES
- IN-LINE INSPECTION OF COMPOSITES
- SCALE-UP OF LAUNCH VEHICLES
- LAUNCH VEHICLE TPS/INSULATION BEYOND 27.5 FT. DIAMETER
- DESIGN & FABRICATION OF THIN WALL CRYOTANKS FOR SPACE EXPLORATION (5-20 FT. Dia.)
7.1.2 Supporting Charts
# REUSABLE VEHICLES SUBPANEL
## VEHICLE SYSTEMS PANEL

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| • CRYOGENIC TANKAGE  
• QUALIFY AL-LI TANKAGE | • SUFFICIENT DATA BASE FOR PROGRAM MANAGERS TO ACCEPT THE MATERIAL IN NEW LAUNCH VEHICLE PROGRAMS |

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| • LIGHTWEIGHT CRYOGENIC TANKS WILL INCREASE THE PAYLOAD TO ORBIT OF VARIOUS LAUNCH SYSTEMS  
• AL-LI HAS NOT REACHED THE MATURITY TO INCORPORATE INTO THE DESIGN WITHOUT CONSIDERABLE ADDITIONAL EFFORT BEYOND THAT CURRENTLY FUNDED. | • CONDUCT A PROGRAM COORDINATED WITH EXISTING PROGRAMS TO ENSURE THAT THE NECESSARY TECHNOLOGY HAS BEEN DEMONSTRATED AND THAT ENGINEERING PROPERTIES INCLUDING AL-HB-5 STATISTICALLY DERIVED PARENT MATERIAL AND WELD PROPERTIES, FRACTURE TOUGHNESS, STRESS CORROSION RESISTANCE, ETC. HAVE BEEN ESTABLISHED |

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</table>
| • CRYOGENIC TANKAGE  
• QUALIFY COMPOSITE TANKAGE FOR USE WITH LIQUID HYDROGEN | |

<table>
<thead>
<tr>
<th>BACKGROUND &amp; RELATED FACTORS:</th>
<th>RECOMMENDED ACTIONS:</th>
</tr>
</thead>
</table>
| • GREATER PAYLOAD TO ORBIT CAN BE OBTAINED WITH COMPOSITE TANKS SUITABLE FOR USE WITH LIQUID HYDROGEN  
• RECENT TESTS WITH A 1/3 FULL SCALE NASP TANK WITH LIQUID NITROGEN (LN2) DEMONSTRATED THAT THE COMPOSITE WAS NOT PERMEABLE AT LN2 TEMPERATURES. EARLIER SMALL SCALE TESTS WITH GASEOUS HELIUM AT -420F DEMONSTRATED TECHNICALLY ACCEPTABLE PERMEABILITY AND RESISTANCE TO MICROCRACKING WHEN THERMALLY CYCLED. NASP 1/3 SCALE TANK IS CURRENTLY IN TEST, THERMAL CYCLE TESTS AND LIQUID HYDROGEN LOADING ARE BEING CONDUCTED. | • ESTABLISH THE ENABLING TECHNOLOGY TO BUILD, INSULATE AND TEST A SUB-SCALE TANK. TANK TEST SUCCESSFUL  
• IDENTIFY WHERE THE TECHNOLOGY IS ADEQUATE AND WHERE DEVELOPMENT IS REQUIRED  
• DEMONSTRATE ADEQUATE TECHNOLOGY  
• DEVELOP TECHNOLOGY (SUBSCALE)  
• DECIDE ON MANUFACTURING APPROACH  
• DESIGN SUBSCALE TANK WITH ALL THE FEATURES OF A FULL SCALE TANK  
• FABRICATE, INSULATE, INSPECT AND TEST TANK WITH LH2 |

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**DESCRIPTION:**
- CRYOGENIC TANKAGE
  - QUALIFY COMPOSITE TANKAGE FOR USE WITH LIQUID OXYGEN

**MILESTONES AND RESOURCE REQUIREMENTS:**
- DEMONSTRATE THE ABILITY TO MEET SAFETY REQUIREMENTS
- FEASIBILITY PROGRAM $500K

**BACKGROUND & RELATED FACTORS:**
- GREATER PAYLOAD TO ORBIT CAN BE OBTAINED WITH COMPOSITE TANKS SUITABLE FOR USE WITH LOX
- RECENT TESTS WITH A 1/3 FULL SCALE NASP TANK WITH LIQUID NITROGEN (L.N2) DEMONSTRATED THAT THE TANK WAS NOT PERMEABLE (IN AN ENGINEERING SENSE) AT LN2 TEMPERATURES. NASP 1/3 SUBSCALE TANK IS CURRENTLY IN TEST. THERMAL CYCLE TESTS AND LIQUID HYDROGEN LOADING ARE BEING CONDUCTED.

**RECOMMENDED ACTIONS:**
- ESTABLISH FEASIBILITY PROGRAM WITH THE FOLLOWING AS A MINIMUM:
  - ESTABLISH SET OF DESIGN GROUND-RULES
  - DEVELOP LINERS WITH DAMAGE THAT WILL PREVENT A CONFLAGRATION
  - TESTS TO DEMONSTRATE NO CONFLAGRATION
  - 1000 CYCLES OF RAPID O2 PRESSURIZATION
  - CONDUCT RAPID FILL WITH PARTICLE IMPINGEMENT
  - BURST TEST

---

**DESCRIPTION:**
- LAUNCH VEHICLE TPS/INSULATION

**MILESTONES AND RESOURCE REQUIREMENTS:**

**BACKGROUND & RELATED FACTORS:**
- CLEAN AIR ACTS MANDATE ELIMINATIONS OF FREON BLOWING AGENTS
- ROBUST DESIGN PHILOSOPHY DICTATES DURABLE TPS SYSTEMS
- LONG DURATION SPACE MISSIONS REQUIRE SPACE QUALIFIED TPS MATERIALS TO SURVIVE ENVIRONMENT AND NOT CREATE DEBRIS FOR OTHER CRITICAL OPERATIONS

**RECOMMENDED ACTIONS:**
- CONTINUE ALS AOP TO DEVELOP ALTERNATE BLOWING AGENTS
- LOOK BEYOND NEAR-TERM FIXES TO FUND LONG-TERM REPLACEMENT MATERIALS
- DEVELOP ROBUST/REUSABLE OR EASILY REPLACEABLE TPS
## REUSABLE VEHICLES SUBPANEL
### VEHICLE SYSTEMS PANEL

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>MILESTONES AND RESOURCE REQUIREMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>- DURABLE PASSIVE THERMAL CONTROL DEVICES AND/OR COATINGS</td>
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<tr>
<th>BACKGROUND &amp; RELATED FACTORS</th>
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<tbody>
<tr>
<td>- REUSABLE CTY PROGRAM REQUIRES LIGHTWEIGHT DURABLE INSULATION FOR MINIMUM COST AND QUICK TURN AROUND</td>
<td>- DEVELOP ROBUST HIGH PERFORMANCE, LOW COST AND REUSABLE THERMAL CONTROL DEVICES AND/OR COATINGS</td>
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<tr>
<th>DESCRIPTION</th>
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<tbody>
<tr>
<td>- DEVELOPMENT AND CHARACTERIZATION OF PROCESSING METHODS TO REDUCE ANISOTROPY OF MATERIAL PROPERTIES IN A-LI</td>
<td></td>
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<tr>
<th>BACKGROUND &amp; RELATED FACTORS</th>
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<tbody>
<tr>
<td>- THE ANISOTROPY OF AL-LI ESPECIALLY THE REDUCED STRENGTH IN THE SHORT TRANSVERSE DIRECTION SIGNIFICANTLY IMPACTS THE UTILITY OF AL-LI APPLICATIONS</td>
<td>- REFINISH EXISTING LABORATORY SCALE PROCESS TO PRODUCE ISOPTROPIC AL-LI</td>
</tr>
<tr>
<td>- DESIGN ALLOWABLES ARE FREQUENTLY DICTATED BY THE S-T STRENGTH (PREVENTING THE ACHIEVEMENT OF MAXIMUM BENEFIT FROM AL-LI USE) AND COMMERCIAL AIRCRAFT BUILDERS HAVE HESITATED TO USE AL-LI BECAUSE OF CONCERN OVER THE LONG TERM EFFECTS OF ANISOTROPY</td>
<td>- SUPPORT SCALE-UP OF LAB PROCESS TO PROTOTYPE COMMERCIAL PRODUCTION VOLUMES</td>
</tr>
<tr>
<td></td>
<td>- CHARACTERIZE MATERIAL PROTOTYPES OF AL-LI PRODUCED BY THESE METHODS</td>
</tr>
</tbody>
</table>
## REUSABLE VEHICLES SUBPANEL  
### VEHICLE SYSTEMS PANEL

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<th>DESCRIPTION:</th>
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<tbody>
<tr>
<td>• DURABLE THERMAL PROTECTION SYSTEM (TPS)</td>
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<tr>
<th>BACKGROUND &amp; RELATED FACTORS:</th>
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<tbody>
<tr>
<td>• FUTURE REUSABLE VEHICLE PROGRAMS REQUIRE LIGHTWEIGHT/DURABLE TPS FOR MINIMUM COST AND QUICK TURNAROUND</td>
<td>• CONTINUE DEVELOPMENT OF DURABLE BOND-ON CERAMIC TILES</td>
</tr>
<tr>
<td>• DURABILITY FOR WIND/RAIN AND SERVICING OPERATIONS IS REQUIRED</td>
<td>• CONTINUE DEVELOPMENT OF DURABLE MECHANICALLY ATTACHABLE METALLIC AND CERAMIC DESIGNS</td>
</tr>
<tr>
<td>• MECHANICALLY ATTACHABLE TPS CAN PROVIDE ACCESS FOR INSPECTION AND REPLACEMENT</td>
<td>• DEVELOP HIGH TEMPERATURE ADHESIVES FOR BOND-ON DESIGNS</td>
</tr>
<tr>
<td>• TPS FOR INTEGRAL LOAD CARRYING CRYOGENIC TANKAGE DOES NOT EXIST</td>
<td>• DEVELOP SPECIFIC TPS DESIGNS FOR INTEGRAL LOAD CARRYING CRYOGENIC TANKAGE INCLUDING HIGH STRENGTH &amp; TEMPERATURE FOAM INSULATION; MAY INVOLVE GROUND PURGE SYSTEM</td>
</tr>
<tr>
<td></td>
<td>• DEMONSTRATE SUITABILITY OF DESIGNS BY FABRICATION AND TESTING TO APPROPRIATE WIND/RAIN, ACOUSTIC, AEROPRESSURE, THERMAL REQUIREMENTS</td>
</tr>
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<tr>
<th>DESCRIPTION:</th>
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<tbody>
<tr>
<td>• UNPRESSURIZED ALUMINUM STRUCTURES (INTERSTAGES, THRUST STRUCTURES)</td>
<td></td>
</tr>
<tr>
<td>• QUALIFY ALU FOR USE WITH UNPRESSURED VEHICLE AND STABILITY LIMITED STRUCTURES</td>
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<tr>
<th>BACKGROUND &amp; RELATED FACTORS:</th>
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<tr>
<td>• MAJOR PORTIONS OF VEHICLE STRUCTURES ARE STABILITY LIMITED. THESE INCLUDE COMPRESSION AND BENDING LOADED STRUCTURES. ALU ALLOYS OFFER INCREASED IN SPECIFIC STIFFNESS OF 20-40% OVER CURRENT ALUMINUM ALLOYS, WITH THE POTENTIAL FOR CORRESPONDING WEIGHT SAVINGS IN THESE STRUCTURES</td>
<td>• FUND DEVELOPMENT AND TESTING OF DEMONSTRATION OF STABILITY LIMITED STRUCTURES (THRUST STRUCTURES, INTERTANK CONNECTORS, WING BOXES)</td>
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<tr>
<td></td>
<td>• COORDINATE WITH LOW COST MANUFACTURING AND NEAR NET SHAPE ACTIVITIES</td>
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</tbody>
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### REUSABLE VEHICLES SUBPANEL

#### VEHICLE SYSTEMS PANEL

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<tr>
<th>DESCRIPTION:</th>
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<tbody>
<tr>
<td>• NEAR NET SHAPE SECTIONS - EXTRUSIONS - FORGINGS</td>
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<tr>
<td>• COST OF SCRAP METAL ON INTEGRALLY MACHINED HARDWARE IS NOT COST EFFECTIVE FOR NEWER METAL ALLOYS • RECENT ADVANCES IN ROLL FORGING AND INCREMENTAL FORGING OFFERS SIGNIFICANT MATERIAL COST AND PART COUNT REDUCTIONS FOR LAUNCH VEHICLES • PROCESS PARAMETERS NEED TO BE DEVELOPED FOR EACH NEW ALLOY</td>
<td>• IDENTIFY CANDIDATE HARDWARE FOR LARGE EXTRUSIONS, ROLL AND INCREMENTAL FORCING PROCESSES • DEVELOP CANDIDATE HARDWARE TO DEMONSTRATE VALIDATE FABRICATION TECHNOLOGY • GENERATE DESIGN ALLOWABLES</td>
</tr>
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### PRESSURIZED STRUCTURES

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<tr>
<td>• PRESSURIZED STRUCTURES COMMONLY USED AS CREW COMPARTMENTS ON SHUTTLE AND SPACE STATION ARE CURRENTLY FABRICATED FROM CONVENTIONAL MATERIALS. • NEW APPLICATIONS SUCH AS NASP, SSTO, AND MVH WILL HAVE GREATER DEMANDS TO REDUCE WEIGHT WHILE BEING SUBJECTED TO HARSHER ENVIRONMENTS • ADVANCED MATERIALS SUCH AS AH AND/OR COMPOSITES HAVE PROPERTIES CONducive TO THE ABOVE REQUIREMENTS. INTEGRAL SKIN AND STRINGER, SANDWICH PANELS, ETC... ARE ALL DESIGNS WHERE THESE MATERIALS WOULD PROVE ADVANTAGEOUS</td>
<td>• CONTINUE DEVELOPMENT OF DESIGN CRITERIA FOR THESE STRUCTURES • CONDUCT DEVELOPMENT TESTS TO DETERMINE THE APPLICABILITY OF THESE MATERIALS TO MEET THE REQUIREMENTS • DESIGN AND FABRICATE TEST ARTICLES TO VERIFY THE APPROACH</td>
</tr>
</tbody>
</table>

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### REUSABLE VEHICLES SUBPANEL

#### VEHICLE SYSTEMS PANEL

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>MILESTONES AND RESOURCE REQUIREMENTS</th>
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</thead>
</table>
| • WELDING AND JOINING  
  - PROCESS UNDERSTANDING, OPTIMIZATION, AND AUTOMATION FOR JOINING STRUCTURES | |

<table>
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<tr>
<th>BACKGROUND &amp; RELATED FACTORS</th>
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</tr>
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</table>
| • REPAIR OF WELDING DEFECTS MAJOR COST IN MANUFACTURING  
  • HUMAN ERRORS A MAJOR CAUSE OF WELDING DEFECTS  
  • LACK OF UNDERSTANDING OF PROCESS VARIABLES AND THEIR INFLUENCE ON PROPERTIES  
  • WELDING USED AS JOINING TECHNIQUE ON ALL MAJOR AEROSPACE HARDWARE  
  • AUTOMATION POTENTIALLY CAN REDUCE NOE | • IDENTIFY PROCESS VARIABLES RELATIONSHIPS  
  • DEVELOP PROCESS MODELS  
  • IDENTIFY AND DEVELOP SENSORS FOR PROCESS MONITORING AND FEEDBACK  
  • IDENTIFY AND DEVELOP CONTROL HARDWARE AND SOFTWARE  
  • VERIFY AND VALIDATE PROCESSES AND CONTROLS  
  • DEVELOPMENT OF TELEROBOTIC CAPABILITY FOR ON-ORBIT REPAIR/MAINTENANCE/INSPECTION |

### MICROMETEOROID AND DEBRIS HYPERVELOCITY SHIELDS

<table>
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<tbody>
<tr>
<td>• MICROMETEOROID AND DEBRIS HYPERVELOCITY SHIELDS</td>
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</table>
| • THE THREAT TO SPACE VEHICLES FROM ORBITAL DEBRIS HAS BEEN RAPIDLY INCREASING  
  • CURRENT ALUMINUM DOUBLE-BUMPER SHIELDING IS VERY HEAVY AND NEWER SYSTEMS SUCH AS NEXTEL HAVE NOT BEEN QUALIFIED | • DEVELOP AND QUALIFY LIGHTWEIGHT SHIELDS AND ATTACHMENT TECHNIQUES  
  • CONDUCT A PROGRAM TO EVALUATE LIGHTWEIGHT SHIELDING DESIGNS TO MEET THE THREAT REQUIREMENTS  
  • ESTABLISH AND VERIFY ANALYTICAL MODELS. GOAL IS TO MINIMIZE SECONDARY EJECT AS WELL AS DEVELOP AND QUALIFY AN ULTRA-LIGHTWEIGHT SHIELDING DESIGN |
## REUSABLE VEHICLES SUBPANEL
### VEHICLE SYSTEMS PANEL

### DESCRIPTION:
- STATE-OF-THE-ART SHELL BUCKLING STRUCTURE OPTIMIZER PROGRAM TO SERVE AS A RAPID DESIGN TOOL

### MILESTONES AND RESOURCE REQUIREMENTS:

### BACKGROUND & RELATED FACTORS:
- CURRENT EMPHASIS ON DEVELOPMENT OF LARGE COMPLICATED FINITE ELEMENT PROGRAMS SUITED TO DETAILED ANALYSIS, NOT DESIGN OPTIMIZATION
- AVAILABLE CODES ARE OUT OF DATE, NOT COMPREHENSIVE AND USER UNFRIENDLY
- WILL IMPROVE THE QUALITY AND SPEED OF BOTH PRELIMINARY DESIGN AND DETAILED DESIGN

### RECOMMENDED ACTIONS:
- PROVIDE FOLLOWING FEATURES
  - MACINTOSH OR WINDOWS USER INTERFACE WITH GRAPHIC DISPLAYS AND PULL-DOWN MENUS
  - SIMPLE USER FORMAT DESIGNED FOR USE BY BOTH DESIGN AND ANALYSIS DISCIPLINES
  - COMPLETE LIBRARY OF STIFFENED SHELL CONFIGURATIONS

### DESCRIPTION:
- TEST PHILOSOPHY
  - RESTRICT STRUCTURAL TEST TO A LOAD FACTOR THAT ALLOWS ALTERNATE USAGES OF EXPENSIVE HARDWARE
  - NO TEST FACTOR

### MILESTONES AND RESOURCE REQUIREMENTS:

### BACKGROUND & RELATED FACTORS:
- HARDWARE HAS BEEN TESTED TO DESTRUCTION OR YIELD TO THE POINT WHERE IT IS UNUSABLE FOR OTHER APPLICATIONS
- STRUCTURES OF ADVANCED MATERIALS PRESENT SIGNIFICANT COST TO PROGRAMS
- "NO TEST FACTOR" MAY BE USED AS AN ALTERNATE WHERE WEIGHT MAY NOT BE CRITICAL

### RECOMMENDED ACTIONS:
- DEVELOP A TEST CODE THAT Restricts TEST TO LOADS WHICH MAXIMIZE THE STRUCTURES "REUSABILITY." INDEPENDENT TESTS SHOULD BE CONDUCTED THAT ALLOW FOR DATA EXTRAPOLATION FROM THE LOWER LEADS TO QUALIFY HARDWARE
### REUSABLE VEHICLES SUBPANEL
### VEHICLE SYSTEMS PANEL

#### DESCRIPTION:
- Reduced Load Cycle Time

#### Milestones and Resource Requirements:

#### Background & Related Factors:
- Long turnaround time load cycles greatly increase cost and restricts implementation of needed changes
- Load cycle costs are excessive

#### Recommended Actions:
- Provide an interdisciplinary loads analysis tool that outputs loads and stress instead of sequential loads and stress analysis
- Develop model synthesis techniques to reduce model development
- Develop an optimized code to reduce computer cost

---

#### Description:
- Structural Analysis Methods

#### Milestones and Resource Requirements:

#### Background & Related Factors:
- Current analysis methods involve analysis being conducted by isolated groups and distributing results to next group in a serial fashion
- Iterations are long and laborious
- Analytical methods, particularly in the area of stability knock-down factors, should be reviewed, updated as necessary and formalized

#### Recommended Actions:
- Develop electronically interfaced, self-checking, analysis tools that allow rapid iteration and apply the benefits of concurrent engineering
- Review available documentation on stability analysis deriving concurrence on knock down factors to be used in above analysis
- Test as required
### DESCRIPTION:
- Optimization of structural criteria

### BACKGROUND & RELATED FACTORS:
- Current structural criteria does not allow assessment of vehicle risk as related to load variability, subsystem redundancy, and factor of safety.
- Lack of simple probabilistic approach to risk assessment stifles examination of required factor of safety to meet program objectives.
- Current approach is to use F.S. ≥ 1.25 for unmanned and F.S. ≥ 1.4 for manned systems.

### RECOMMENDED ACTIONS:
- Develop simple probabilistic approach with necessary data to derive and justify structural criteria.
- Develop analysis tools to implement structural reliability approach and selection of factors of safety.

---

### DESCRIPTION:
- Develop an engineering approach to properly trade material and structural concepts selection, fabrication, facilities, and cost (total cost).

### BACKGROUND & RELATED FACTORS:
- Structural simplicity reduces assembly cost and operational cost.
- Processing can increase cost, MR hardware, and lower margins (sensitivities).
- Total cost is the driver, not just weight.
- Sequential engineering is costly.
- Sequential engineering tends to hide sensitivities and proper trades.

### MILESTONES AND RESOURCE REQUIREMENTS:

### RECOMMENDED ACTIONS:
- Develop concurrent engineering tools (all disciplines) that properly trade between material, structural concept, fabricating facilities, performance, and operation.
- Develop optimization criteria for total cost.
7.2 PROPULSION SYSTEMS PANEL
7.2.1 Final Presentation